# SCIENCE IN GLASS PRODUCTION

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## ANALYSIS OF SERVICE OF REFRACTORIES IN GLASS-MELTING TANK FURNACES

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The fundamental issues of extending the period between repairs for glass-melting tank furnaces are analyzed. Based on data obtained in studying refractory brickwork after the furnace has been stopped for a cold repair and analyzing the specifics of corrosion of refractories in various structural elements, technical solutions are proposed and implemented enabling one to extend the tank furnace campaign to 7 – 8 years.

The overhaul period for a glass-melting tank furnace depends on many factors: properties of refractory materials, primarily their heat and corrosion resistance in the melt and in the aggressive gaseous atmosphere saturated with aggressive volatile glass and batch components and fuel combustion products, as well as service condition of brickwork elements (cooling, insulation), glass melting parameters (temperature level, specific glass melt output, type of fuel) and furnace design specifics.

The significant service properties of refractories determined under laboratory conditions cannot provide a sufficiently accurate estimate of the furnace campaign duration. They can be used for comparison of various materials and preliminary estimate of their suitability for specific service conditions. Consequently, objective data on efficient and rational application of refractory materials can be obtained only by a systematic study of their behavior in various structural elements of brickwork. A generalized analysis of such data may identify the ultimate service capacities of traditional refractories and suggest effective solutions regarding an upgrade of the furnace design, improvement of the service condition of brickwork elements, or replacing a refractory by another more resistant one, in order to extend as much as possible the furnace campaign.

The database obtained at the Salavatsteklo JSC during the past 30 years from numerous inspections of brickwork of glass-melting tank furnaces for sheet and container glass and impure sodium disilicate after the furnaces were stopped for a cold repair or reconstruction during the last 309 years indicates that the service life of a furnace is usually limited not by the general unsatisfactory state of the whole brickwork but by the destruction (frequently an emergency destruction) of a limited number of structural elements in the melting tank and the gas space of the melting zone with maximal temperatures.

Such elements primarily include:

– the upper part of the melting tank walls;

– burners and walls of the flame space;

– roofs and dividing walls of regenerator chambers and regenerator checkerwork;

– to a lesser extent the main roof and the bottom of the melting tank in the same zones.

Its should be noted that up to 1990s when a campaign usually lasted 3 – 4 years, the limiting element was usually the upper part of the melting tank walls. In recent years when the campaign of the tank furnaces at the company has been extended to 7 – 8 years, the elements limiting the furnace campaign are more often the upper structure elements (burners, flame space walls, certain parts of regenerators).

Below we consider the most wearable elements of the refractory brickwork of glass-melting furnaces and the specifics of their destruction in real service conditions.

**Melting tank walls.** This element of brickwork for a long period was the main element limiting the campaign duration. The corrosion of the melting tank walls at the level of the glass melt surface in the contact site of three different phases used to lead to a complete wear of this part (Fig. 1).

Statistic processing of furnace inspection data established that the main factors responsible for the corrosion of melted-cast baddeleyite-corundum (bacor) refractories on the specified sites are the maximum glass-melting temperatures

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**Fig. 1.** Melting tank wall after the furnace was closed for cold repair.

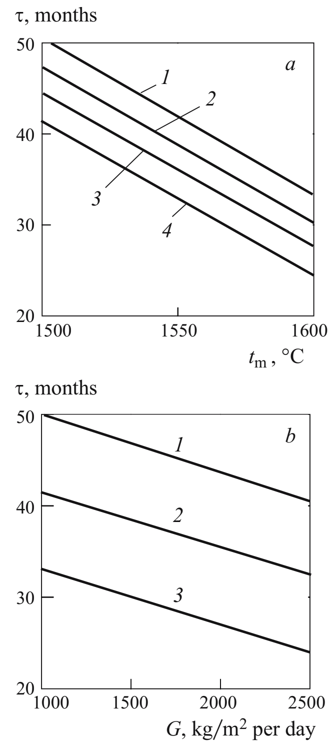


**Fig. 2.** The duration of corrosion of beams of melting tank walls to residual thickness of 30 mm versus the maximum melting temperature (*a*) under specific glass melt output of 1000 (*1*), 1500 (*2*), 2000 (*3*), and 2500 kg/m$^2$ (*4*) per day and versus specific glass melt output from the melting part of the furnace (*b*) at maximal melting temperatures of 1500 (*1*), 1550 (*2*), and 1600°C (*3*).

and the specific output of glass melt per surface area of the melting zone of the furnace. Summarized data on the effect of the specified factors on the rate of corrosion of this part of the wall to a residual thickness of 30 mm are given in Fig. 2. The initial thickness of the beams was equal to 250 mm and the intensity of forced air cooling of their external surface was 0.7 – 0.8 m$^3$/sec per 1 m of brickwork.

The analysis of obtained dependences demonstrates that the maximum melting temperature $t_m$ has a significantly greater effect on the rate of the wall corrosion at the glass melt level expressed via the time τ of reaching the residual thickness of 30 mm than the specific melt output *G*. Thus, raising $t_m$ by 50°C (from 1550 to 1600°C) with $G$ = 1500 – 2000 kg/m$^2$ per day shortens the time of reaching the residual thickness of 30 mm by 30 – 35%, whereas an increase in *G* by 500 kg/m$^3$ per day (from 1500 to 2000) at $t_m$ = 1550 – 1600°C decreases it by only 7 – 9%. Evidently, the effect of the kinetic factors on accelerating the corrosion process has more weight than the mechanical factors, considering the low velocity of glass melt near the walls of the melting tank wall (up to 10 m/h). Note that the insignificant effect of glass melt flows on the destruction of the melting tank walls is noted in the classical work of Prof. N. V. Solomin.

The dependence shown in Fig. 2 makes it possible to justified the time of installing additional plates on the melting tank wall at the glass melt level, which is currently considered the most efficient solution extending the service life of this brickwork element. Thus, in a furnace with $t_m$ = 1550°C and $G$ = 1500 kg/m$^2$ per day using domestic refractory bacor 33, new plates have to be installed after 33 – 39 months of service, whereas in a furnace with $t_m$ = 1600°C and $G$ = 2000 kg/m$^2$ per day new plates have to be installed after 26 – 28 months. Note that the use of more resistant refractory materials or more intense forced air cooling may significantly extend the initial period of failure-free service of this brickwork element up to the first installment of additional plates.

As for the quality of material for melting tank walls, the domestic bacor refractories are still significantly inferior to their western analogs regarding their service resistance, which is the main parameter. This is primarily due to the enhanced inhomogeneity of texture over the beam volume, with large areas of shrinkage porosity, caused by their production in reducing conditions, which determined the low melting point of the vitreous phase, its insufficient corrosion resistance, and increased propensity toward formation of glass melt defects. The quality parameters of domestic and foreign products of this class are compared in [2, 3].

The low quality of domestic bacor refractories when used in critical structural elements of glass-melting furnaces has a crucial influence on the campaign duration and prevents extending it beyond 7 – 8 years, whereas abroad this parameter has already reached 12 – 15 years.

**Burners, walls and arches of the flame space.** The burners and walls of the flame space in the considered furnaces were constructed from two types of refractories: dinas and bacor 33. These refractories in service differed fundamentally.

The destruction of dinas parts of brickwork elements (Fig. 3) under the effect of aggressive volatile batch components, especially alkali components was sufficiently intense and manifested in fusion of surface sites, which required frequent hot repairs, sometimes with a total replacement of

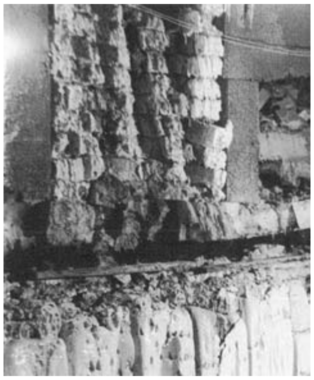

**Fig. 3.** Destruction of dinas brickwork elements of the melting part of the furnace.

**Fig. 4.** The state of regenerator elements in the end of the furnace campaign.

some elements, for instance, the burner cheeks and stringers in the melting and maximum temperature zones.

The chemical analysis of dinas samples from the flame space walls and burners indicated the presence of up to 2.5 – 4.0% $Na_2O$. However, according to the data in [4], the content of 3 – 4% $Na_2O$ in dinas decreases its softening temperature to 1550°C and 5 – 6% $Na_2O$ decreases it to 1450°C. The additional direct impact of the flame on the surface of the specified refractory elements produces local superheating up to temperatures frequently exceeding the maximum melting temperature. Therefore, the use of dinas in the brickwork of burners and walls of the flame space is not advisable. To improve the service reliability of these elements and extend the furnace campaign, they have to be constructed from more resistant bacor refractories.

At the same time, the service of bacor refractories in these elements also has certain specifics [5]. Under the effect of aggressive volatile components a thin reaction layer is formed on the refractory surface, which consists of badelleyite crystals, a vitreous phase, and newly formed crystal phases: cordierite, spinel, mullite, and alkali aluminosilicates. The mechanical strength of this layer, considering the low heat resistance typical of domestic bacor, is insufficient, which leads to its frequent peeling and caving, with corrosion extending deep into the refractory brickwork. Consequently, frequent defects in the analyzed glass-melting furnaces are spalling of the tips of bacor prongs, cracking and spalling of individual stones in burner inlets and in the furnace hopper arches, sometimes with their emergency collapse [6]. Thus, in this case as well the quality of domestic bacor refractories, primarily their structural inhomogeneity and low thermal resistance, are responsible for insufficient service reliability of the considered elements.

To restore the working state of the upper furnace structure, ceramic welding is successfully used at the company [7]. Unfortunately, in our country only dinas brickwork is repaired in this way. Yet the introduction of the hot repair technology for bacor elements could significantly extend the glass-melting furnace campaign.

Note as well that intense corrosion of refractory elements frequently occurs in joints between the flame space walls and burner inlets, on the one hand, and dinas heels (beams protecting the heels) of the main roof, on the other hand. An effective method for improving the service reliability of this part of the furnace is installing an additional row of highly resistant refractories above the burner inlets and flame space walls.

**Regenerators.** The main purpose of the service reliability of regenerators is ensuring their failure-free operation and full elimination of hot repair in all their structural units: regeneration chamber roofs, partitioning walls, and checkerwork. This can be primarily attained using highly resistant high-periclase refractories and for checkerwork using special profiled high-periclase or melted-cast refractories [8]. The specialists of our company are aware of this problem and intend to exclude numerous (virtually continuous) hot repairs for restoring refractory brickwork and replacing regenerator checkerwork in the course of the furnace campaign.

Such repair operations are not only material-consuming and labor-consuming since they are conducted in hard conditions, but also essentially disturb a steady glass-melting regime, increase power consumption, and degrade the quality of products.

It should be noted that the reasons for the fast destruction of dinas refractory elements are the same as in the case of the burners and flame space walls. Naturally this process is further accelerated by the periodic (every 20 – 30 min) flame reversal, which periodically creates a significant temperature difference (up to 300 – 400°C) within a very short time. Under such conditions not only dinas, but magnesian refractories as well, experience intense corrosion (Fig. 4).

A positive effect on decreasing the rate of corrosion of regenerator chamber roofs can be obtained by raising the roof with respect to the checkerwork and introducing an additional row of beams above the inlets and the walls between the burners.

Lately regenerator checkers in the glass-melting furnaces at the Salavatsteklo company are made of standard domestic periclase bricks P91 No. 9. However, even using this refrac-

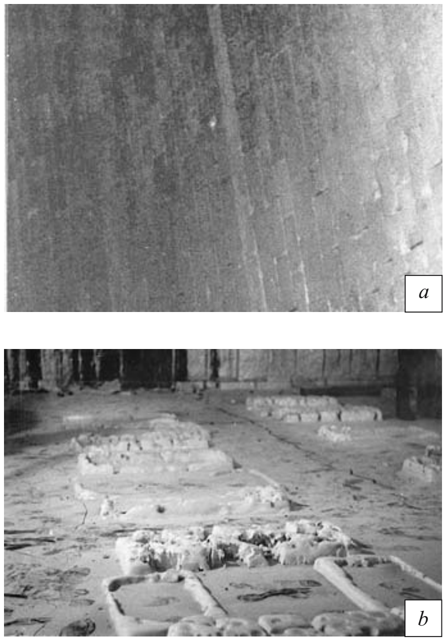

**Fig. 5.** The inner surface of the main roof (*a*) and the bottom of the melting tank (*b*) after the furnace was closed for cold repair.

tory, the average service life of checkers is no longer than 3 – 3.5 years, due to their insufficient corrosion resistance because of a low content of MgO (90 – 91%) and a high content of impurities.

Note also that ceramic welding is much more easy, convenient, and efficient for a hot repair of a regenerator, which is widely used in our glass-melting furnaces.

**The main roof and bottom of the melting tank.** These refractory elements of tank glass-melting furnaces are arbitrarily included in the list of the most wearable elements, only because some glass factories experience serious difficulties in servicing these structural units.

At our company the main roof of tank furnaces made of glass dinas and open-hearth dinas from the Dinur Works (Pervouralsk) has served well throughout the campaign (over 7 years) and actually did not experience significant corrosion (Fig. 5*a*). We have registered only slight fusion in the first and the second sections with brickwork thickness decreasing by 5 – 10 mm, whereas in the remaining sections the inner roof surface actually did not undergo any thermal or structural changes.

In our opinion, such situation of the dinas main roof is due to high-quality sealing and heat insulation of its outer surface, using the classical variant including a zircon-phosphate sealing paste, quartz sand, dinas lightweight brick, mullite-silica fibers, and polished aluminum sheets. Note that insulation and especially thorough sealing of joints actually prevents the corrosion of dinas brickwork in the roof.

As for the bottom of the melting tank, we have developed and implemented a multilayer heat-insulated tank bottom, which has that has high service reliability and makes it possible to level the glass melt temperature gradient across the tank depth with significant saving of fuel (2 – 5%) and improving the chemical and thermal homogeneity of the glass melt. The only difficulty in the service of the tank bottom is installing nozzles for glass melt swirling; however, for this purpose we have developed and implemented a special bubbling unit ensuring high service reliability of this brickwork element (Fig. 5*b*).

Having brought the duration of glass-melting furnace campaign to 7 – 8 years, our specialists now intend to extend it to 10 – 12 years. We are sure that all newly constructed or reconstructed glass-melting furnaces will function reliably for this period.

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